Detector Research at Fermilab

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Users Meeting

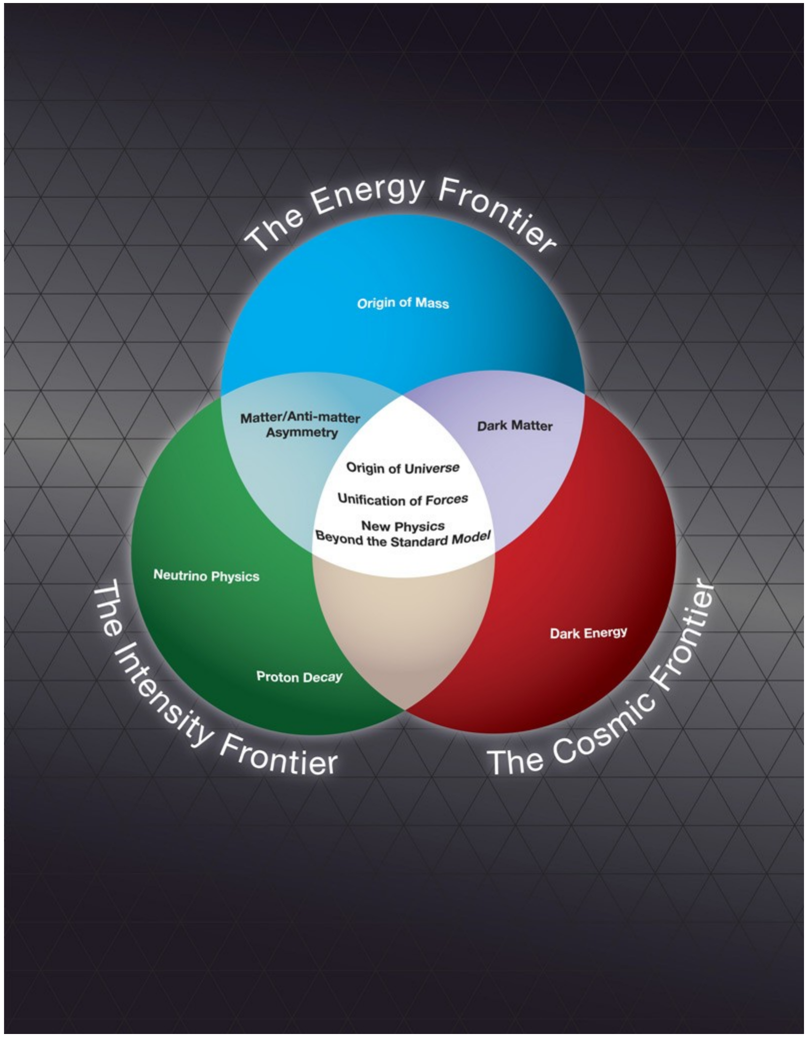
2 June, 2010

The Frontiers of the Field

- The '3 frontiers' outline the major thrusts of high energy physics:
  - 'Energy': includes lepton and hadron collider detectors
  - 'Intensity': neutrino and rare decay experiments
  - 'Cosmic': dark matter and dark energy

- In each area, the physics is advancing rapidly. It is crucial that the detector technology keep pace.

- Fermilab is making major contributions in each of these frontier areas.



Why Fermilab?

- Detector R&D at Fermilab should be geared towards our strengths as a national lab. Typically this means that the lab's institutional capabilities come into play. These can be
  - Presence of unique facilities
  - Experienced, well established engineering groups
  - Managing projects that are too large for an individual university
  - Projects that require a large initial investment

- In almost all cases there is a high degree of collaboration with the university community or other (inter)national labs.

CALICE at the test beam

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Inspection at SiDet

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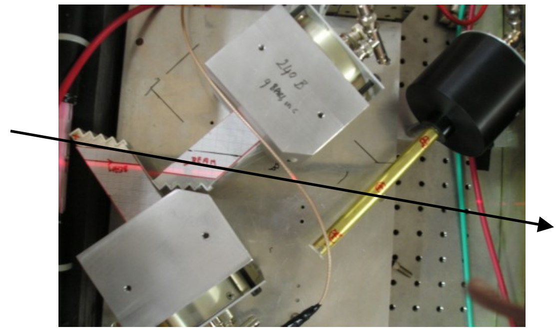
Liquid Argon purity Demonstrator

As examples of detector R&D questions, Why don't we….?

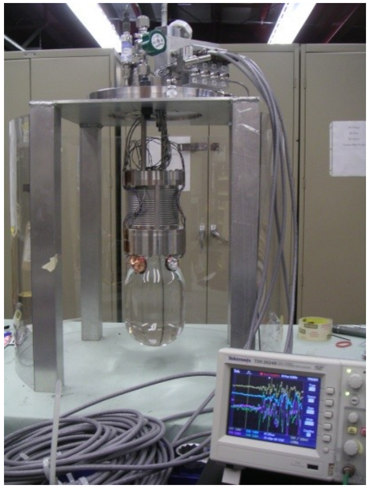
- Make silicon sensors in 3 dimensions instead of 2
- Read out detectors with light instead of cables
- Make hadronic calorimeters out of crystals
- Smash the 100 psec barrier in time-of-flight
- Fill liquid Argon tanks without evacuating them
- Freeze Xenon into a solid crystal, instead of using liquid
- Perform particle identification…

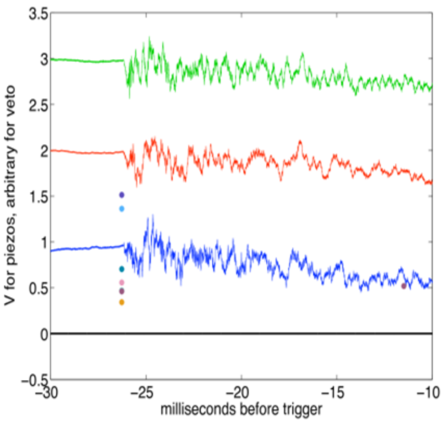


(15 psec resolution quartz TOF devices)

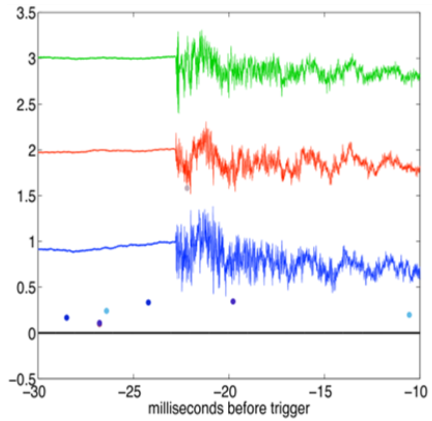
With sound waves?

COUPP 4 kg Test Chamber





Neutron interaction



α Decay

I. 3-Dimensional Silicon

The development of 3D integrated circuits has recently received much attention in trade journals, special sessions have been arranged at various IEEE meetings, and dedicated meetings such as 3D Architectures for Semiconductor Integration and Packaging have taken place.

All of this attention is generated by industry seeking to perpetuate Moore's Law. In particular, industry is focusing on several 3D IC applications:

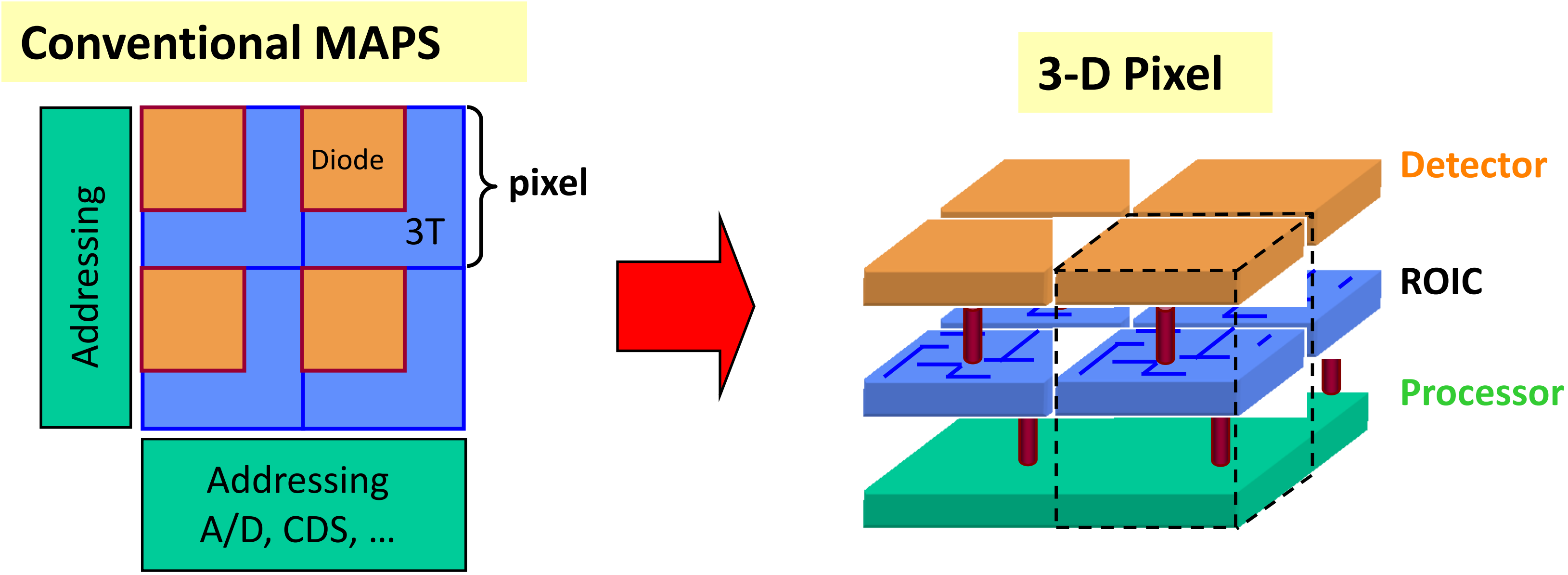
- stacked memory chips
- pixel arrays for imaging
- logic and memory stacking on microprocessors and FPGAs.

The 3D technology is being driven entirely by industry. However, the time has come when HEP can begin to benefit from work in progress.

Fermilab began exploring 3D technology for HEP several years ago and submitted the first 3D IC (VIP1) for HEP to MIT Lincoln Labs in October 2006.

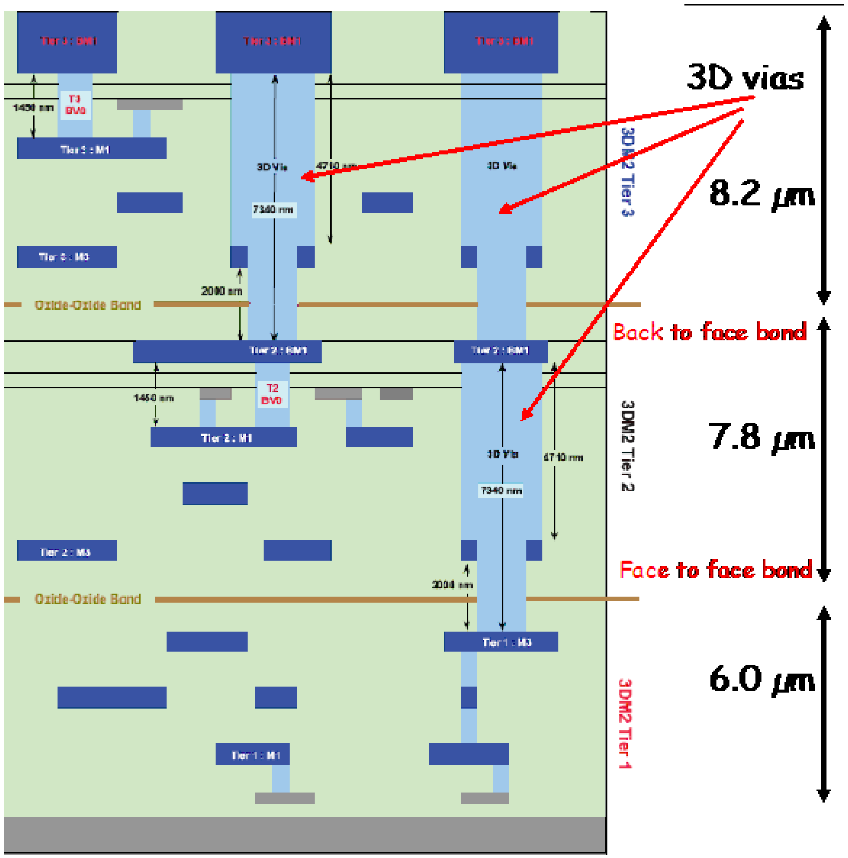
3D = Vertical Integration

- Vertical integration of thinned and bonded silicon tiers with vertical interconnects between the IC layers



Milestones Achieved in First HEP 3D Circuit called VIP1

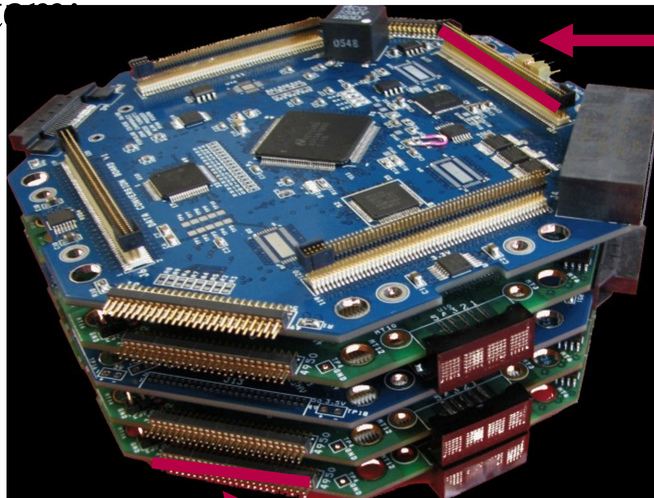
- Demonstrated increased circuit density by integrating 3 circuit tiers
- Showed that extreme circuit thinning (7um) was possible
- Showed that small vias (~1.5 um) were possible thus allowing for small pixel sizes.
- Showed that 3D vias and bonding were reliable



MIT LL 3 Tier Assembly

II. The CAPTAN DAQ system

- The CAPTAN DAQ system has been developed by the DIG (Detector Instrumentation Group) of CD/ESE. There are 3 basic concepts behind the system:



1)Vertical standard bus

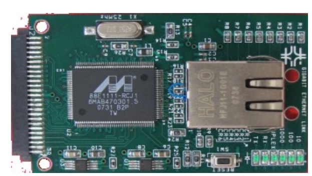
2)A set of core boards:

NPCB – Node Processing and Control Board

DCB – Data Conversion Board

3)Horizontal connectivity

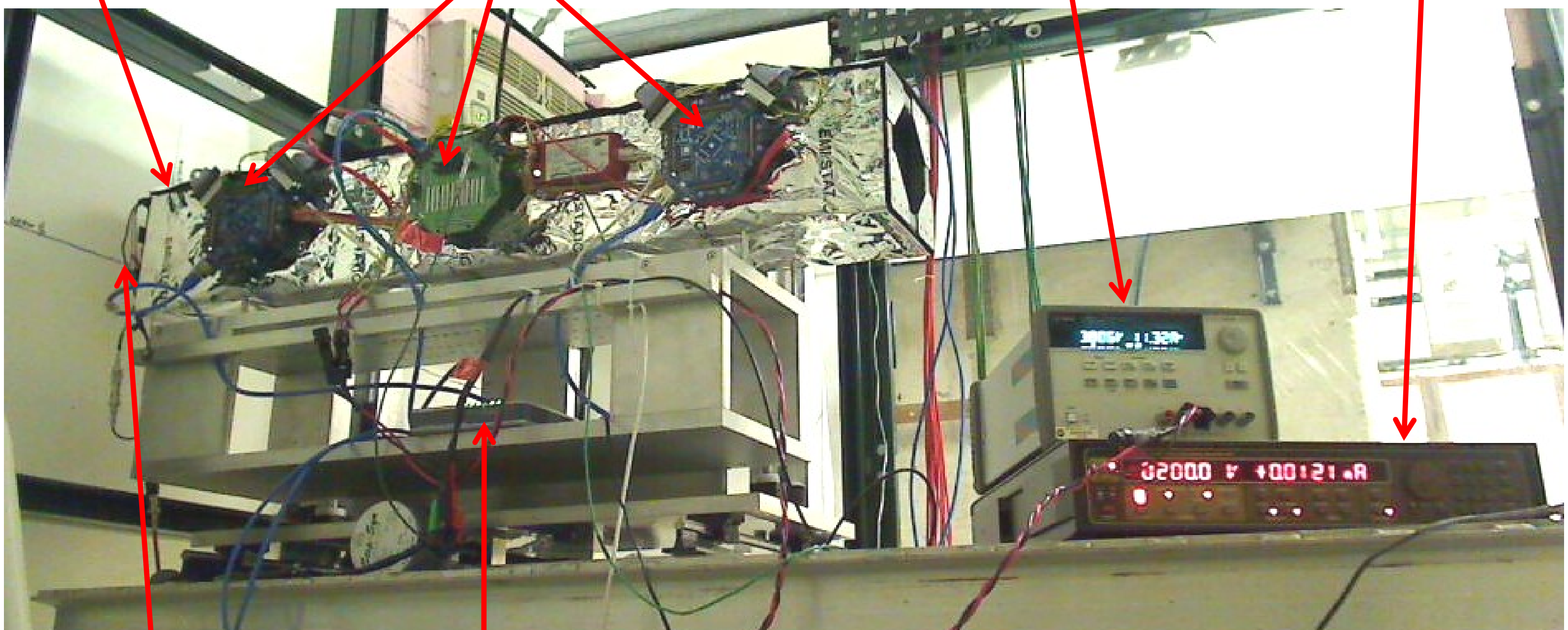
- **Gigabit Ethernet Link**
- **Interface Boards**
- **Level Translator**
- **USB**



- The software is a multithreaded application running on windows

Test Beam Pixel Telescope Overview

TELESCOPE BOX CAPTAN STACK POWER SUPPLY DUT SENSOR BIAS

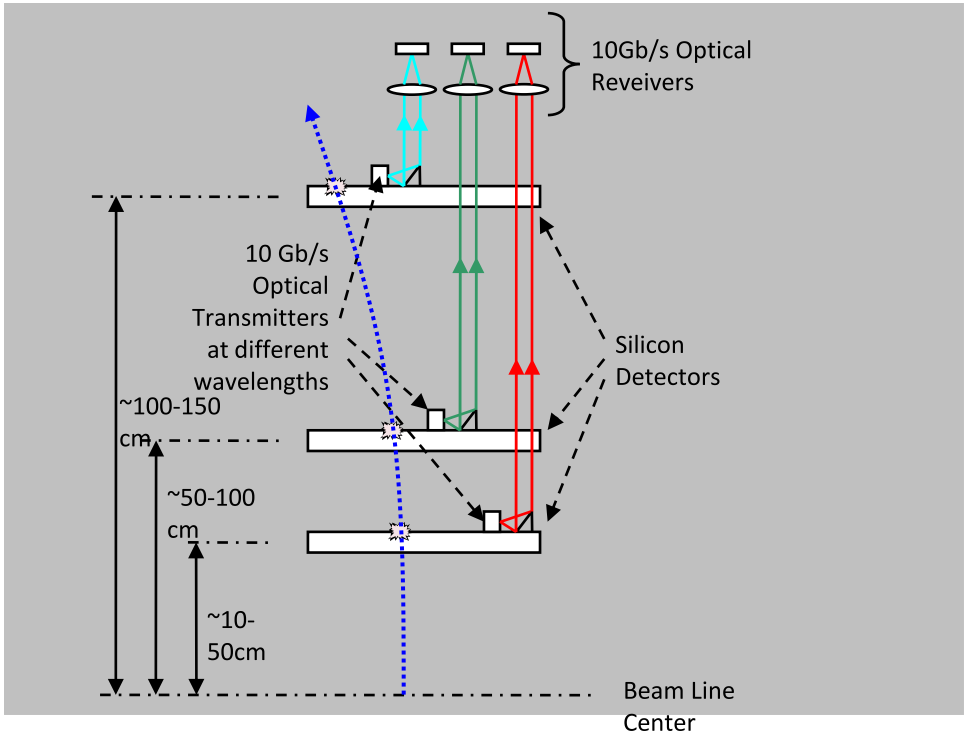


SCINTILLATOR ROUTER

A great example of the synergy between detector development, Fermilab's unique facilities (test beam, in this case) and the User community, which now benefits from this added capability.

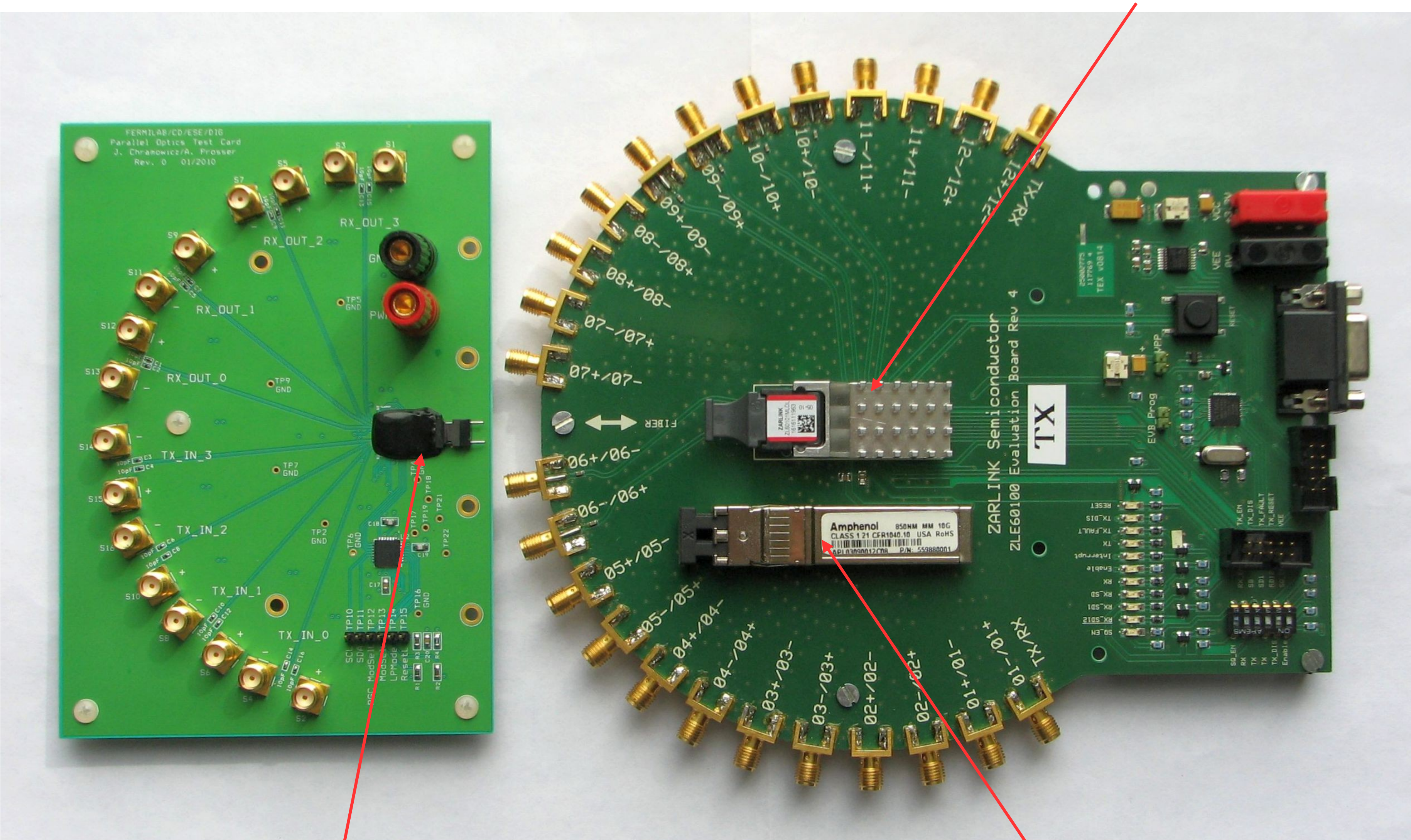
III. Free-Space Optical Interconnects for Cable-less Readout in Particle Physics Detectors

- **The Problem:** Future particle physics experiments at the high energy frontier will all require large arrays of silicon detectors making data transmission cumbersome.
- **The Solution:** Vega Wave Systems proposes to design and develop a free-space optical link for trigger and data extraction.
- The novelty and feasibility of this system is based upon the fact that the silicon detectors are transparent to the infrared wavelengths (1.4 micron) of the optical data link.
- Two Phase 1 SBIR proposals submitted with Fermilab as partner
- Rather than waiting for the outcome, since February, we have been working with Vegawave on a demo test-stand.



A conceptual sketch of a free-space optical link for data extraction and trigger functions in a vertex detector.

SNAP12 Tx (2.7 Gbps/channel)



4x4 Optical Engine Transceiver (6.25 Gbps/channel)

SFP+ Single Channel TRx (10 Gbps)

IV. Technical Issues for Liquid Argon TPC-based detector being addressed at Fermilab

Chemical purity of Argon to allow electron drift ***(neutrino and DM)***

Chemical purity of Argon to allow light propagation *(DM)*

HV feedthroughs (>100 kV) in Argon gas ***(neutrino and DM)***

TPC design ***(neutrino and DM)***

Wire readout *(neutrino)*

Light Detection ***(neutrino and DM)***

Data Acquisition ***(neutrino and DM)***

Cryogenics (and associated safety issues) ***(neutrino and DM)***

Detector Materials Qualification ***(neutrino and DM)***

Shielding from environment radiation *(DM)*

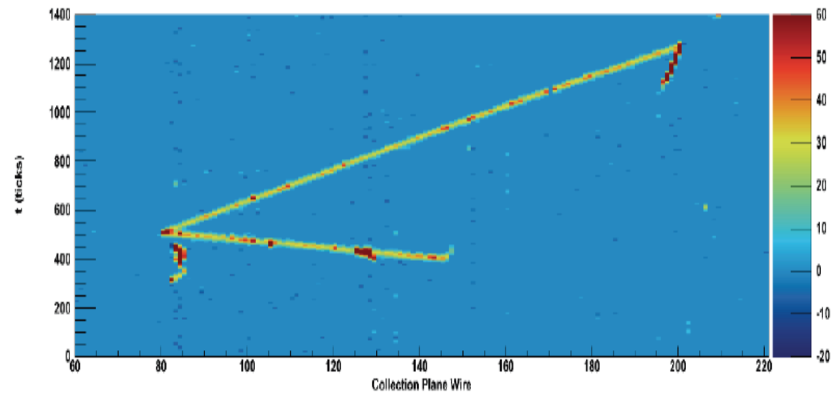
Radio-purity of detector materials *(DM)*

Liquid Argon Setup for Materials Testing and TPC Readout

Atmospheric Argon has activity of 1 Bq/kg from ^{39}Ar, which is a source of background and pile-up in multi-ton Argon based Dark Matter detectors. Underground Argon has been shown to be depleted in ^{39}Ar by at least a factor of 25.

Distillation Column at the PAB was designed at Princeton and assembled at Fermilab, for the separation of underground Argon from the accompanying Nitrogen and Helium.

ArgoNeut succeeds in capturing and analyzing the first low energy neutrinos (<10 GeV) seen in a liquid Argon TPC.



Can this be scaled up so that it competes with water Cerenkov detectors for long baseline neutrino detectors?

“LAPD” = Liquid Argon Purity Demonstrator

• Primary goal is to show that required electron lifetimes can be achieved without evacuation in an empty vessel - Phase I

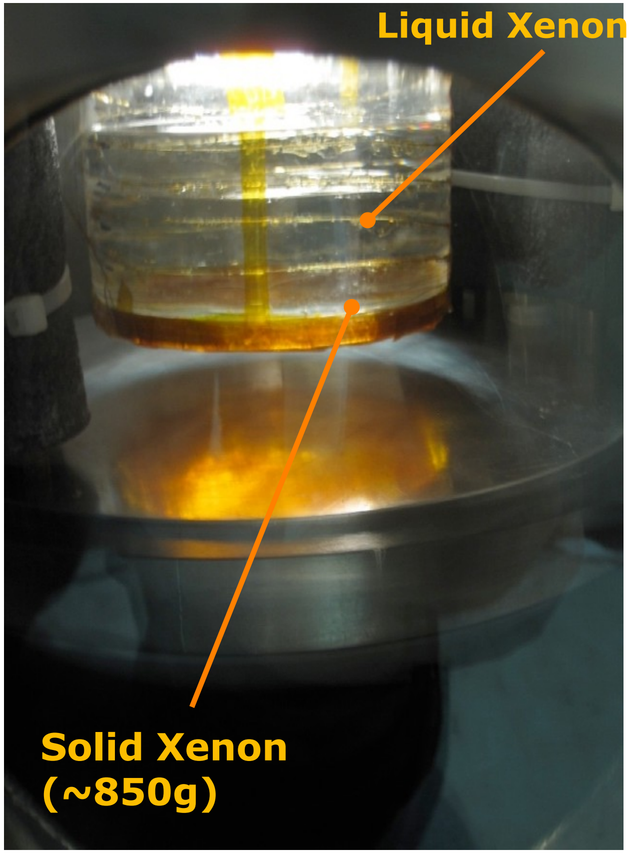
• Will also monitor temperature gradients, concentrations of water, O2, and N2

• Phase II will place materials that would be used in a TPC into the volume and show that the lifetime can still be achieved

• Possible Phase III upgrade could place an actual TPC in the volume to provide a test bed for electronics, light collection, etc

VII. Solid Xenon Detector R&D Project

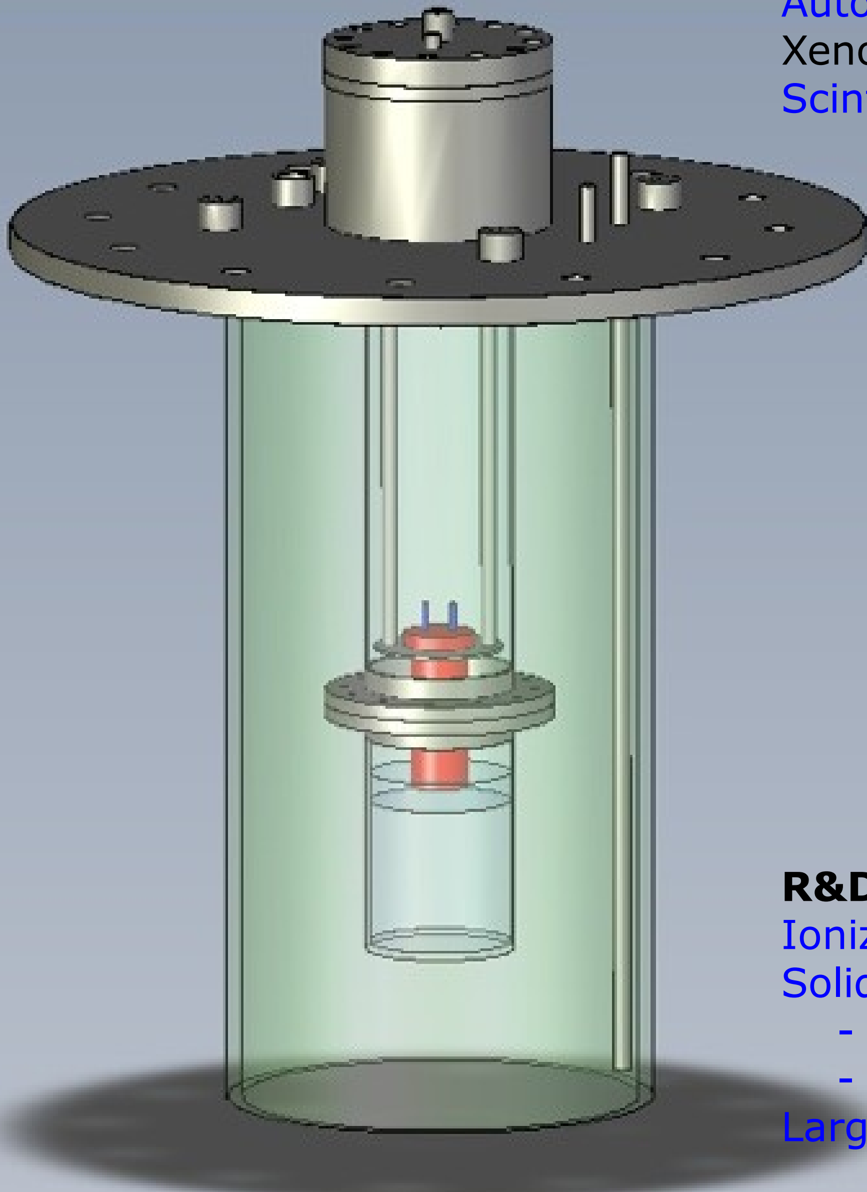
Low Background Science
- Solar axion search
- Dark matter search
- Neutrinoless double beta decay



Why Xenon?
- No long-lived Xe radio isotope
- High yield of scintillation light
- Easy purification (distillation, etc)
- Self shielding : Z=54

Why Solid Xenon?
- Bragg scattering
- Simple crystal structure : fcc
- More scintillation light (solid > liquid)
- Drifting electrons faster
- No further background contamination through circulation loop

R&D Phase-1 Completed
- Collaboration with U.Florida and TAMU
- Build optically transparent solid xenon
- Detailed recipes ready

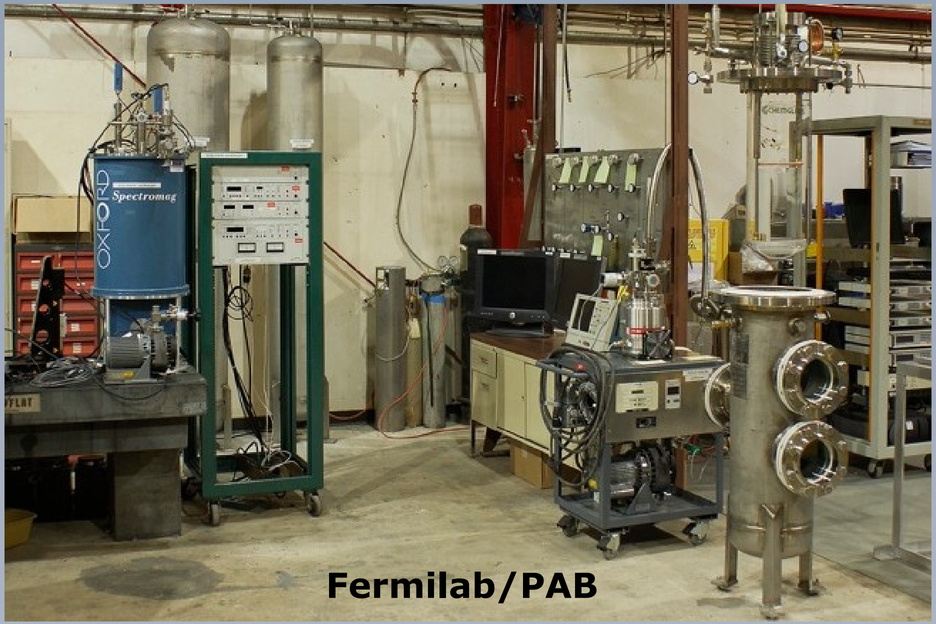


R&D Phase-2: Scintillation Light Readout (Now)

Automatic controller setup for crystal growth

Xenon purification system and mass spectroscopy

Scintillation light measurement from solid xenon



R&D Phase-3: Ionization Readout (Plan)

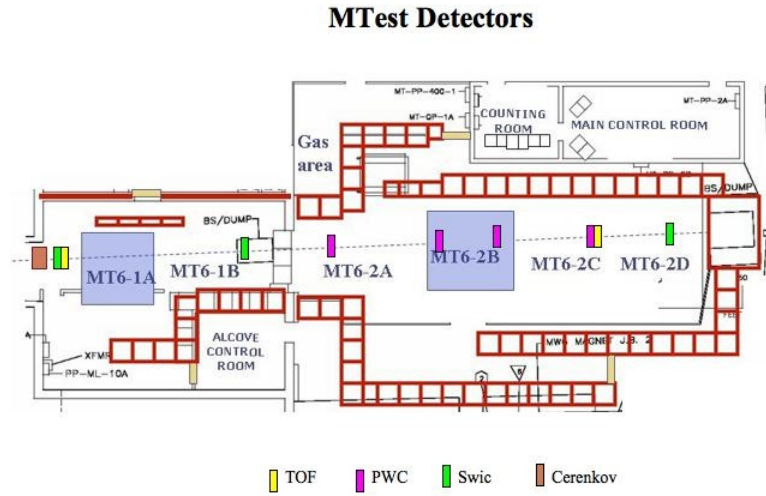
Ionization readout

Solid Xenon property measurement

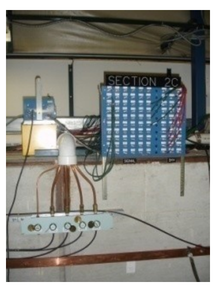
- Transparency, absorption, index of refraction …
- Low temperature characteristics (~4K)

Large solid xenon crystal growth (>10kg)

VIII. Fermilab's Test Beam Facility



Spacious control room



Signal and HV cables

Gas delivery to 6 locations

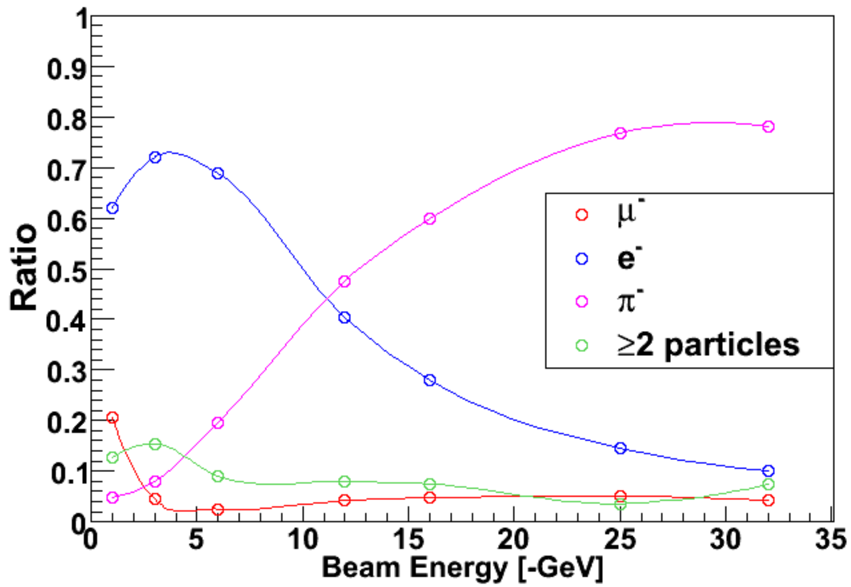
4 station MWPC spectrometer

Two motion tables

Beam Rates and Electron Content

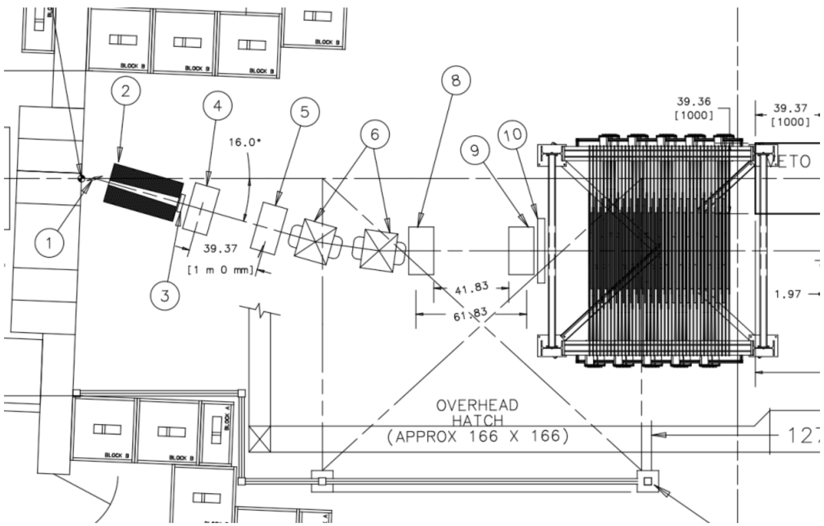
Measured rates (normalized to 1E11 at MW1SEM)

Beam Energy (GeV)	Rate at Entrance to Facility (per spill)	Rate at Exit of Facility (per spill)	%Pions, Muons**	% Electrons**
16	132,000	95,000	87%	13%
8	89,000	65,000	55%	45%
4	56,000	31,000	31%	67%
2	68,000	28,000	<30%	>70%
1	69,000	21,000	<30%	>60%



Tertiary 300 MeV/c Beamline for MINERVA

- The MINERVA experiment requested space to create a new tertiary beamline that could deliver particles down to 300 MeV/c momentum.
- The Particle Physics Division and Accelerator Division have agreed to help and are proceeding on installation.
- Full tracking and TOF will allow for momentum measurement and particle i.d.



Apologies, for a lack of time, to:

- High Finesse Holographic Interferometry
- CMB B-field polarization
- Argo-Neut Liquid Argon TPC
- Dual readout calorimetry
- CCD low recoil energy dark matter detector
- 21-cm Baryon Acoustic Oscillation Experiment
- Silicon Photomultiplier characterization
- …

Our Web Site: http://detectors.fnal.gov

- a work in progress!

Are we doing our job?

- **In the Energy frontier, we are:**
  - Advancing silicon detector construction into a new 3D realm.
  - Beginning work on understanding how to build a dual readout calorimeter
  - Developing low cost, high performance DAQ systems for the R&D community
  - Investigating optical data transmission for detectors

- **In the Intensity frontier:**
  - Operating Liquid Argon test stands to test for the effect of materials on charge drift and purity.
  - Built and ran the first U.S. Liquid Argon TPC to operate in a neutrino beam
  - Established the world's fastest beamline time-of-flight system

- **In the Cosmic frontier:**
  - Learning about acoustic response to various backgrounds in a bubble chamber, for dark matter detection
  - Growing solid Xenon crystals for axion and rare neutrino interactions.
  - Utilizing CCD's for low mass dark matter searches.

- **Backed up by our facilities:**
  - ASIC design
  - Silicon detector fabrication
  - Cryogenic engineering
  - Particle test beam

We invite the R&D community to work with Fermilab to develop strategic partnerships in detector research !